August 25, 2003

Fermilab-LBNL Collaboration Meeting Summary

Fermilab August 5-6, 2003

The meeting was organized at Fermilab with the goals of discussing common issues related to the Fermilab and LBNL magnet programs and to define and strengthen areas for collaboration. Discussions included the base programs in High Field Accelerator Magnet R&D, LARP magnet R&D, Nb_3Sn strand and cable R&D for the base and LARP programs, and support of the national SC R&D program.

The list of participants is presented in Appendix I. There were 9 participants from LBNL and 21 participants from Fermilab. Three representatives from ASC-UWM and 3 representatives from BNL (via video link) took part in the Strand and Cable session.

The meeting agenda is presented in Appendix II. Parallel sessions were held on Nb_3Sn magnet R&D and Strand and Cable studies with several joint sessions and discussions. A tour to Fermilab's Magnet Test Facility and Magnet Workshop was organized for all participants.

Meeting discussions are summarized below:

1. Programs

Fermilab and LBNL magnet groups have intensive superconducting magnet R&D programs directed toward the development of Nb_3Sn-based accelerator magnets for future upgrades of existing HEP facilities next-generation applications. Both groups have the infrastructure and intellectual resources necessary for successful R&D programs in accelerator magnet and superconductor technology development.

Traditionally, the LBNL magnet R&D program has been oriented toward the development of innovative proof-of-principle model magnets with an emphasis on obtaining the highest possible fields. During the past ten years, the LBNL magnet group developed and tested several successful models with magnetic fields above 10 T, reaching a record field of 14.5 T in a common coil configuration. An integral part of the program is the use of sub-scale magnets based on small racetrack coils that are used to evaluate materials and mechanical design issues, study performance and develop fabrication techniques.

The Fermilab high field magnet program is focused on the development of full-size accelerator magnet prototypes with operating fields in the range of 10-12 T which meet all the technical requirements applied to accelerator magnets - field range, field quality, operating margin, thermal stability, quench protection, etc. and are cost effective in terms of production and operation. The Fermilab magnet group has tested three short dipole models and demonstrated the possibility of reaching required field quality in Nb_3Sn magnets. The observed poor quench performance is being studied and optimized using the magnetic mirror configuration.

A number of significant developments and successes over the past several years has laid the groundwork for rapid progress in further development of innovative technologies for the use of brittle superconductors and magnet components. A short list includes different

Rutherford-type cables with low degradation, with and without a stainless steel core; ceramic insulation with ceramic binder or pre-preg; design and fabrication methods for metallic end parts; mechanical structures and techniques based on bladders; passive correction techniques based on thin iron shims, development of integrated analysis tools, etc.

An important opportunity for the R&D effort that builds on the success of the U.S. base programs is the recently approved U.S. LHC Accelerator Research Program or LARP. The LARP magnet program is very challenging, and will require close collaboration of the U.S. magnet groups. Strong base magnet R&D programs at Fermilab and LBNL are critical for the success of this program.

Both groups participate in the DOE Conductor Development Program, and provide support through their extensive infrastructure related to the R&D of superconducting strand and cable.

2. Magnet Sessions

FNAL

We discussed the designs and technologies developed at Fermilab for Nb_3Sn dipoles based on the wind-and-react approach. Some results related to the mechanical analysis and all fabrication steps were described. Presentations were illustrated by pictures of different steps in the manufacturing process. LBNL magnet experts visited the magnet workshop where they could see the winding process of the cos-theta dipole coil with S2-glass insulation and ceramic binder, samples of coil end parts, tooling and converse one-on-one with the engineers and technicians involved in the process.

Discussions of design and fabrication were followed by the presentation and discussion of magnet test results with particular focus on quench performance. Possible explanations of limitations in magnet quench current including splice damage, conductor stability, boundary induced coupling currents (BICC's), etc. were presented and discussed.

LBNL

The LBNL group presented the designs of different racetrack magnets developed at LBNL, magnet fabrication technology and summary of magnet test results. Special attention was given to the bladder design and parameters, and magnet assembly using the bladder technique. There was particular interest by the FNAL cos-theta dipole design team in D20 fabrication and assembly. A list of questions, presented to the LBNL D20 experts, were subsequently answered and returned.

During the tours and discussions, a couple of variations in fabrication procedures were noted :

- *The FNAL process for installing voltage taps after epoxy potting could damage either the epoxy or cable depending on the temperature of the process; this is not monitored during soldering.*
- *The potting process is similar to that at LBNL except FNAL removes the potted coil from the vacuum chamber and puts it in an oven for curing. This doesn't allow the epoxy to backfill from the reservoirs.*

Based on discussions during the meeting, the following were found to be of common interest for application in both programs and possible joint studies.

Magnet design and fabrication

1. Cable insulation
2. Coil winding and curing with liquid binder or ceramic pre-preg
3. End part design and fabrication
4. 3D mechanical models and analysis
5. Mechanical structures and techniques with coil prestress using bladders
6. Coil prestress measurement and control

Magnet testing and data analysis:

1. Observation of voltage spikes and correlation with magnetic and mechanical instabilities
2. Noise reduction and compensation of inductive components to improve observation of resistance growth before and after quench detection
3. Cable resistance measurements in the coil/cable as a function of temperature
4. Determination of quench origin
5. Field measurements
6. Mechanical measurements
7. Thermal measurements in the coil
8. Explore ways to facilitate the exchange of test data, i.e. standard presentation formats

3. Strand and Cable Session

Four groups participated in this discussion—BNL (via videolink), FNAL, LBNL, and U. Wisconsin. The overall impression is that considerable progress in strand testing has been made since the initial meeting on strand testing issues was held at ASC 2002. At the time of ASC, all groups listed above, as well as the strand manufacturers, were having difficulties obtaining good V-I curves for the high Jc strands at high currents. Stable V-I curves could be obtained by some groups at high fields where the transport currents were relatively low, but the strands became unstable at lower fields and higher transport currents. Several possible causes of unstable behavior were discussed, including sample motion, sample damage (especially at the Ti barrel to Cu ring transition), heating in the sample to holder contact region, and finally, an intrinsic stability problem associated with the large effective filament size and high Jc of these samples. At this meeting, all groups reported significant progress in obtaining smooth V-I curves for the high Jc strands at fields B=12T and higher. E. Barzi of FNAL showed examples of measurements of Nb_3Sn strands at low fields B<8-10T (in fact for 0.7 mm strands it was observed at I<1 kA) that could be attributed to intrinsic strand instabilities. In contrast, the results shown by D. Dietderich of LBNL indicate stable behavior for Oxford RRP 6445 (0.8 mm) 1,007 A @ 11.5 T with self-field. LBNL is in the process of upgrading its current supply to 2000 A and attempt to reproduce FNAL's results. This is an important issue, since strand instability is being discussed as a source of the low current quench behavior seen in the FNAL cos theta magnets.

Barzi reported:

- No significant contact heating during Jc tests.
- No sample motion during a quench with or without stycast.

Ghosh, comments on stability:

- Heating could occur from micro-motion of conductor during Jc test.
- Could be intrinsic to strand (?).

Cooley, comments on stability:

- Change (increase) the temperature during Jc measurements to change (increase) the heat capacity of the strand (FNAL has done that)
- Change the time constants for magnetic diffusion and thermal diffusion (how?)

The other main topics of discussion were cable critical current and cable interstrand resistance measurements. These tests are important as well in understanding whether strand and/or cable instability is a source of the low current quench for the Nb_3Sn magnets.

At present, there are no facilities capable of testing the high current Nb_3Sn cables being used in the magnets at FNAL and LBNL. The BNL facility that is being used to test NbTi LHC cable is limited to about 8.5 T (including cable self field), and 25 kA. The FRESCA test facility at CERN has a higher field (10 T) and higher current (35 kA) capability. The main technical requirement in order to utilize FRESCA is the design and fabrication of a holder for Nb_3Sn samples. This is an area where FNAL and LBNL are collaborating. Discussions at this meeting focused on the sample holder requirements and on a division of tasks so that we can develop a common sample holder in the shortest time. When the design is complete, the capabilities and costs of this approach will be weighed against the capabilities and costs of the subscale coil tests. If it appears that cable testing in the CERN facility is complementary to the subscale coil tests, sample holders will be fabricated and a cable test program will be implemented in collaboration with CERN.

The final topic was interstrand resistance measurements for cables. G. Ambrosio presented some preliminary results that show a strong dependence on sample preparation techniques. His plan near term is to develop techniques for making measurements on actual coil sections, rather than relying on sample stacks. Since he is developing this capability, it will be useful to send several LBNL coil sections to FNAL so that we can have coil measurements to compare with the cable stack measurements that LBNL have already obtained (LBNL/OST/Twente collaboration).

The action items that emerged from the strand and cable testing sessions are:

1. Institute an inter-laboratory testing plan that aspires to test the high current density HEP Nb_3Sn strands. The testing plan and a list of specific measurements for each test should be prepared for presentation at the November 2003 LTSW.
2. LBNL and BNL will upgrade their current testing capabilities from 1000 to 2000 A. This will allow the two Labs to investigate instabilities in the same range of field and current as FNAL.
3. Fermilab and LBNL will proceed on the design of a Nb_3Sn sample holder for use at FRESCA.

4. LBNL will prepare coil sections for interstrand resistance measurements at FNAL.
5. Fermilab and LBNL in collaboration with others will continue to push ahead with the development of high-Jc Nb3Sn strand that will have a Deff of 50 microns or less.

4. Small racetrack coils

Small racetrack coils were developed at LBNL and successfully used for testing a variety of cable and structural concepts in fields up to 12 T. The magnet mechanical structure is based on the bladder assembly technique. This approach is of particular interest to Fermilab for testing cables used in their high field model magnets and evaluating the instability hypothesis. Discussion of this approach included presentation of the Fermilab plans for initiating the small racetrack coil program, design modifications and preliminary mechanical analysis, as well as presentation of the LBNL design, results and plans for the future. During the discussion special attention was given to the modifications implemented in the Fermilab coil structure in order to accommodate wide, full-scale cables. Fermilab's schedule was also presented and discussed. Based on these discussions we will continue collaborative efforts in this area in order to implement the small racetrack technique at Fermilab.

5. Next steps.

During the meeting we also discussed the issues related to further development and strengthening of the collaboration. The following directions have been discussed and supported:

a) joint experiments

Examples of past collaborative interactions are:

- LBNL design and fabrication of end-parts of Fermilab's first Nb_3Sn dipole
- Cable fabrication for some of FNAL's model magnets
- Joint thermal shock experiment using LBNL sub-scale coils
- LBNL tests of ceramic insulation and binder used in FNAL's cos-theta models

Some future collaborative topics could include:

- Develop integrated program to study Fermilab's stability model using small racetrack coils
- development and fabrication of cable sample holder for cable testing at CERN
- fabrication and test of quadrupole technological models for LARP at Fermilab
- Further development of tools required to perform complicated magnetic, mechanical and thermal models for the analysis of high field magnets

b) personnel exchange

In order to provide better exchange of ideas and experience we will organize visiting of experts for short (up to 2 weeks) and long (up to few months) period of time for participation in collaborative experiments and studies related to magnet and component fabrication, testing and data analysis.

c) next collaboration meetings

Both groups recognize the importance of regular collaboration meetings and mini-workshops for discussions of the results and coordinating R&D plans. The frequency of these meeting should be 2-3 times per year. Topics for future meetings will include:

- Status and perspectives of the react-and-wind approach as a technology for high field accelerator magnets based on brittle superconductors
- LARP magnets: conceptual design studies and technology development
- High field magnet mechanics
- High field magnet quench performance
- Quench protection issues (particularly using ANSYS)
- Field quality in Nb_3Sn accelerator magnets
- Heat depositions and magnet cooling
- Spend more time discussing details of analysis, fabrication techniques and test results.

Appendix I

List of participants

LBNL:

1. Scott Bartlett
2. Shlomo Caspi
3. Dan Dietderich
4. Paolo Ferracin
5. Steve Gourlay
6. Ray Hafalia
7. Roy Hannaford
8. Al Lietzke
9. Ron Scanlan

Fermilab:

1. Giorgio Ambrosio
2. Nicolai Andreev
3. Emanuela Barzi
4. Sri Bhashiyam
5. Bernardo Bordini
6. Deepak Chichili
7. Luciano Elementi
8. Sandor Feher
9. Vadim Kashikhin
10. Vladimir Kashikhin
11. Bob Kephart
12. Jim Kerby
13. Mike Lamm
14. Eric Marscin
15. Igor Novitski
16. Phil Schlabach
17. Rich Stanek
18. Daniel Turrioni
19. Ryuji Yamada
20. Victor Yarba
21. Alexander Zlobin

Other organizations:

ASC-UWM

1. A. Godeke
2. A. Squitieri
3. M. Jewell

BNL (via Video link)

1. L. Cooley
2. A. Ghosh
3. R. Soika

Appendix II

Meeting agenda

August 5, 2003		
8:30-12:00 a.m.	**HFM and SC R&D status (**Chair: V. Yarba**)**	
8:30-8:45	Welcome	B. Kephart
8:45-9:30	LBNL SCM base program	S. Gourlay
9:30-10:15	Fermilab HFM base program	A. Zlobin
10:15-10:30	*Coffee break*	
10:30-11:00	LARP magnet R&D	S. Gourlay
11:00-11:30	SC development program	R. Scanlan
11:30-12:00	Tour to IB1-MTF, ICB-LHCIRQ and IB3-HFM	
12:00-13:00	*Lunch, discussions*	
1:00-5:45 p.m.	**Session I: Nb_3Sn magnet R&D** (Chair: S. Caspi)	
1:00-1:45	HFDA and HFDM design and technology	D. Chichili
1:45-2:30	HFDA and HFDM test results	S. Feher
2:30-3:00	Tour to IB3 and discussion	
3:00-3:15	*Coffee break*	
3:15-4:00	LBNL magnet design and technologies	R. Hafalia/R. Hannaford
4:00-4:45	LBNL test results	A. Lietzke
4:45-5:45	Discussion	
1:00-5:45 p.m.	**Session II: Strand and cable studies** (Chair: R. Scanlan)	
1:00-1:15	Strand testing at Fermilab	E. Barzi
1:15-1:30	Strand testing at LBNL	D. Diederich
1:30-1:45	Strand testing at UWM	A. Goedeke
1:45-2:00	Strand testing at BNL (via video link)	A. Ghosh
2:00-2:30	Discussion of strand testing issues	
2:30-3:00	Tour to SC R&D Lab	
3:00- 3:15	*Coffee break*	
3:15-3:45	Strand stability measurements	E. Barzi
3:45-4:15	Strand stability calculations	V. Kashikhin
4:15-4:45	Interstrand resistance measurements	G. Ambrosio
4:45-5:00	Cable testing at BNL	A. Ghosh
5:00-5:45	Discussion	
7:00 p.m.	*Dinner*	
August 6, 2003		
8:00-10:00 a.m.	**Discussion of magnet test results and analysis**	

10:00-10:15 a.m.	*Coffee break*	
10:15-12:00 a.m.	**Small racetrack coils** (Chair: E. Barzi)	
10:15-10:30	Small racetrack coils at Fermilab: status & plans	E. Barzi
10:30-11:00	Small racetrack design, mechanical analysis, fabrication	S. Bhashyam
11:00-11:15	Small racetrack coils at LBNL: status & plans	S. Gourlay
11:15-12:00	Small racetrack design, mechanical analysis, instrumentation, fabrication	P. Ferracin/R. Hannaford
12:00-13:00	*Lunch*	
1:00-2:30 p.m.	**Discussions and meeting summary**	
2:30 p.m.	*Adjourn*	